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Process Parameters Optimization for Continuous Infrared Rice Bran Stabilizer and Assessment of Their Impact on Quality and Shelf Life

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ABSTRACT

Background: Rice bran is the most valuable by-product of the rice milling operation. The FFA level rises immediately after milling and bran oil becomes hazardous for consumption owing to its lower pH, rancid flavor and soapy taste.

Methods: A continuous-type infrared rice bran stabilizer was designed and process parameters such as moisture content, thickness, power density and treatment time were optimized for their impact on FFA content of bran, capacity and energy demand of the stabilizer using response surface methodologies. Under constant power density and moisture content, it has been confirmed that the capacity decreases with infrared exposure time.

Result: The capacity was minimum (6.7 kg/h) at 0.5 cm thickness and 5 min exposer times, whereas it was maximum (40.2 kg/h) at 1 cm bed thickness and 3 min exposer time. The energy demand rose as the power density and time of exposure increased while the bed thickness and moisture content remained constant, whereas the FFA lowered nonlinearly as the power density and exposure time increased. FFA content was shown to be low at lower bed thickness and moisture content and to increase slowly as thickness and moisture content increased to 0.8 cm and 15% (w.b), respectively. However, when bed thickness and moisture level increase further, FFA content raised dramatically.

Key words: Infrared stabilization, Process optimization, Response surface methodology, Rice bran stabilization.

INTRODUCTION

Rice is being cultivated on over 44 million hectares in India with productivity of 2,400 kg per hectare and produced about 110 million tonnes of rice during 2016-17 (SEA, 2017). In the rice milling industry, one of the valuable by-products is rice bran. The bran contains a substantial amount of protein, fat and dietary fiber in addition to minerals (such as magnesium and potassium) and vitamins (such as thiamine, riboflavin, niacin and pyridoxine) (Esa *et al*., 2013). Rice bran oil fatty acid comprises of 41% monounsaturated, 36% polyunsaturated and 19% saturated (Kahlon, *et al*., 1992). When the bran layer separated from the endosperm during milling, the lipase enzyme is activated, resulting in the breakdown of fat into free fatty acids (FFA) and glycerol. The FFA level rises immediately after milling and bran oil turns unsafe for consumption due to its decreased pH, rancid flavor and soapy taste (Rosniyana *et al*., 2009). Therefore, adopting an appropriate stabilization technology capable of inhibiting rancidity and microbiological activity is essential to preserving rice bran after milling and enhancing its quality and shelf life (Ju and Vali, 2005).

Different methods employed for rice bran stabilization are dry heat treatment (Yu *et al*., 2019), microwave treatment (Patil *et al*., 2016), ohmic heating (Dhingra *et al*. 2012), extrusion (Sharma *et al*., 2004), infrared radiations Wang *et al*. (2017) γ-irradiation, parboiling (Pradeep *et al*., 2014); (Thanonkaew *et al*., 2012) and toasting (Silva *et al*., 2006). Moist heat treatments like steam retorting are costly, while extrusion cooking is very expensive in terms of operating, initial and maintenance costs (Dhingra *et al*., 2012). Since the thermal energy of infrared radiation (IR) is directly absorbed by food products without warming the surrounding air, it has been regarded as a promising method for food processing (Skjöldebrand, 2001). It offers numerous benefits over traditional heating technology, such as uniform heating, adaptability, simple equipment, quick heating time, minimal quality losses and low energy usage (Irakli, *et al*., 2018; Kathiravan *et al*., 2007). Yan *et al*. (2020) demonstrated that IR processing may adequately ensure rice bran stability in terms of desired fatty acid compositions, appropriate enzyme activities and aroma attributes. This process may be

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designed using appropriate equipment that is simple, easy to control, automatable and safe (Sakai and Hanzawa 1994) while ensuring low processing time, energy consumption and capital expenses (Yilmaz, 2016). Most scientists have used the batch-type infrared stabilizer for rice bran stabilization, which requires more process time with limited capacity. Hence, the objective of the study is to develop a continuous rice bran stabilizer and optimization of infrared heating operational parameters (moisture content, thickness, power density and time) with respect to maximizing the capacity and minimizing the FFA.

MATERIALS AND METHODS

Rice bran

Freshly milled, full-fatted raw rice bran (Long grain Variety: MTU-2716) was obtained from a rice mill. Prior to stabilization, the raw bran was sieved using an 18-mesh sieve to remove impurities such as rice husk, clay, wood, sawdust, *etc*. Cleaned rice bran was sealed in an aluminium foil bag and refrigerated at -18°C till the experiment was completed.

Stabilization of rice bran

A prototype continuous infrared rice bran stabilizer (Fig 1) has been developed and used for fresh rice bran stabilization. The designed continuous infrared rice bran stabilizer is constructed of a galvanized angular iron frame measuring 15×27×70 cm in size. A 15×20 cm Teflon belt rides on 5 cm diameter and 22 cm long rollers and is driven by a 110 cm pulley with a 2.5 cm driver pulley from a 2 HP variable frequency drive motor to achieve a 44:1 speed ratio. A 1.1m short wave infrared emitter is mounted at a constant height of 15 cm from the bed. In an arc roof construction, a stabilizer chamber of 125×95 cm aluminium sheet with a thickness of 1mm has been used to offer the greatest reflection of infrared radiation on the belt. The radiation intensity of the emitter was altered by changing the voltage using a continuous autotransformer and measured by a pyranometer. A stainless steel feeding chute with dimensions of 50×18×6 cm and a stainless steel product delivery chute with dimensions of 40×12×8 cm are welded to the frame. Before the bran enters the stabilization chamber, the thickness of the bran on the belt will be adjusted using a shutter plate on the feeding chute. Exposer time of rice bran to infrared radiation was adjusted by controlling the belt speed. Treated rice bran was collected through the delivery chute.

Design of experiments and statistical analysis

The performance of continuous rice bran stabilizer was studied for processing at different treatments with different operational parameters namely moisture content (X_1), thickness (X_2), power density (X_3) and time (X_4) to study their effect on different parameters such as FFA and capacity. To reduce many experiments, with four independent variables, a central composite rotatable design (CCRD) and Response Surface Methodology (RSM) has been successfully applied to optimize operational parameters (Table 1). About thirty trials were carried out in accordance with the CCRD (Table 2) and their combined effects from Response Surface Methodology (RSM) were examined using Design Expert-11 software, which yielded optimal values based on the criteria shown in Table 3.

Quality analysis of rice bran

Oxidative rancidity deterioration is caused by a reaction between lipids and molecular oxygen. The process of inactivating deteriorative enzymes in fresh rice bran is known as stabilization and its shelf life is evaluated in terms of free fatty acids.

Moisture content

Moisture content was determined by the oven-dry method as the loss in weight due to evaporation from the sample at a temperature of 105°C. The weight loss is represented as the amount of moisture present in the sample (AOAC, 1990).

Determination of temperature

Treated bran was collected in a paper cup and promptly, the temperature of the bran was measured with non-contact infrared thermometer (RayTemp, UK), which measures temperature over the range of -60°C to 500°C with an assured accuracy of ±1°C.

Determination of fat content

The total fat content of the rice bran was estimated using Soxhlet extraction (SOCS Plus, SCS06 ASDLS) for 4 h with n-hexane (AOAC, 1984).

Estimation of free fatty acid

About 1-10 g of the oil sample was mixed with 100 mL of neutralized alcohol and kept on a hot plate for 10-15 minutes. Two drops of phenolphthalein indicator were added and titrated against 0.1N KOH until consistent pale pink color was obtained (Ermosele, 1994).

$$\text{Free fatty acid (\%, oleic acid)} = \frac{\text{Titre value} \times 28.1 \times 0.1}{\text{Sample weight, g}}$$

Determination of energy consumption and power density

An electrical meter (Watt-hour meter, Power tech measurement system, Delhi, India) was used to calculate energy use (Power Density). The energy consumption in kilowatt-hours is calculated by continually monitoring the instantaneous voltage and amperes. The IR emitter's and electric motor's combined energy consumption was measured in kWh kg^{-1} rice bran.

Determination of capacity of the IR stabilizer

The capacity of the continuous rice bran stabilizer was determined by collecting the rice bran from the collection chute for 5 min and capacity was calculated by following formula.

$$\text{Capacity (kg/h)} = \frac{\text{Treated rice brancollected, kg}}{\text{Time, h}}$$

Packaging and storage of treated samples

Treated rice bran samples were placed in polyethylene zip-lock bags and the moisture content and FFA have been determined prior to storage at 4°C in the refrigerator. FA levels were taken at 10-day intervals for the best sample.

RESULTS AND DISCUSSION

Statistical analysis Table 2 summarizes the experimental results of capacity, energy demand and FFA content under various treatment conditions. Statistical analysis showed that the proposed model was valid with acceptable R^2 values for all the responses and non-significant lack of fit. The R^2 values for capacity, energy demand and FFA content were 0.989, 0.917 and 0.916, respectively. The empirical model more accurately represents the real data when the R^2 value is higher. The lower the R^2 value, the less relevant the dependent variables in the model must explain variation in behavior (Little and Hills, 1982; Mendenhall, 1975). All regression models had probability (p) values less than 0.000, indicating that there was no lack of fit.

Effect of exposure time and bed thickness on rice bran stabilizer capacity

The capacity increased as the thickness of the rice bran bed increased at constant power density and moisture content, as seen predicted response surface plot (Fig 2). The capacity was minimum (6.7 kg/h) at 0.5 cm thickness and 5 min exposer time, whereas it was maximum (40.2 kg/h) at 1 cm bed thickness and 3 min exposer time. The quantity of material carried on the conveying belt at every turn of the belt increases as the thickness of the rice bran bed rises, resulting in an increase in the capacity of the stabilizer. It has been indicated that under constant power density and moisture, capacity declined with infrared exposure time. Infrared exposure time is proportional to the speed of the conveyor belt, *i.e.*, as belt speed increases, infrared exposure time reduces. Since the amount of material released per unit time increases, the speed of the conveying system increases and the capacity of the stabilizer increases. As a result, reducing the exposure time enhances the continuous infrared stabilizer's capacity.

The experimental data can be adequately fitted using quadratic model (p-0.001). F-value (201.14) revealed that the capacity had been significantly impacted by the linear terms of independent variables (thickness, time) and their interaction terms. The second-order nonlinear regression model has been developed based on the actual values of the independent variables moisture content (X_1), thickness (X_2), power density (X_3) and time(X_4) for the dependent variable capacity. Equation-(1) provides the derived correlation with real values (after the non-significant components have been eliminated).

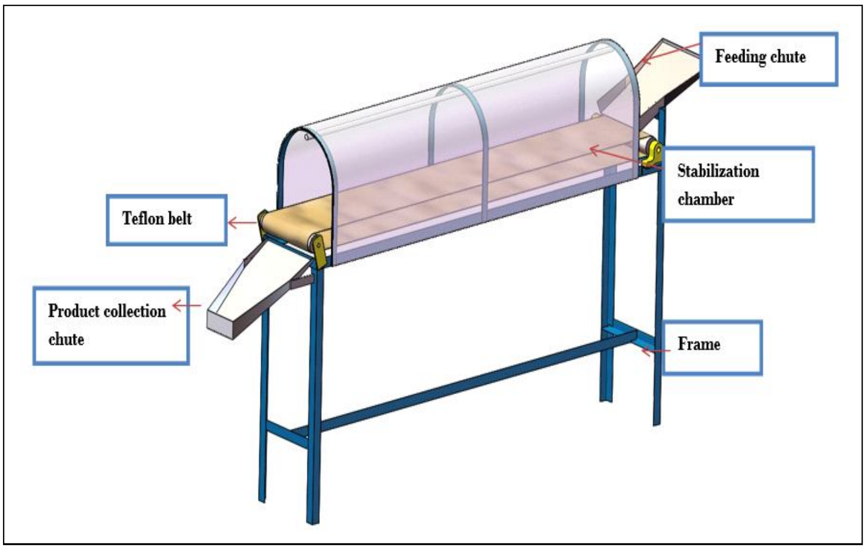

Fig 1: Continuous infrared rice bran stabilizer.

Table 1: Real values and coded values used in CCRD.

Independent variables	Data levels				
	-α (-1.682)	-1	0	+1	+α (+1.682)
Moisture content, %	9	12	15	18	21
Power density, W/m²	150	300	450	600	750
Time, min	2	3	4	5	6
Thickness, cm	0.25	0.50	0.75	1.00	1.25

Capacity =

$$24.33+0.002\,X_1+0.191\,X_2+57.977\,X_3-13.39\,X_4-7.15\,X_3X_4-0.0006360\,X_2^2-0.9158X_3^2+1.685X_4^2 \quad \ldots(1)$$

Predicted R^2 of 0.9695 and adjusted R^2 of 0.9898 are reasonably in agreement; that is, the difference between the two values is less than 0.2, indicating that the derived model is quite well-fitted. The values of the CV (4.07) and APR (52.749) indicate that the experiment and model had appropriate accuracy and consistency.

Energy requirement of stabiliser as a function of exposure time and power density

For the interaction of independent variables on energy demand, the model-predicted response surfaces are shown in Fig 3. It has been demonstrated that the energy requirement increased as power density and exposure duration increased at constant bed thickness and moisture content. While power density and exposure duration increased, energy consumption increased as well, peaking at higher power densities and longer exposure times. The energy demand varied between 0.006-0.015 $kWhkg^{-1}$. The most often used method of stabilizing rice bran in the literature, extrusion at 130°C for a short period, followed by holding the bran for three minutes at 97-99°C before cooling, was estimated to consume 0.076 $kWhkg^{-1}$ of energy. Additionally, it was claimed that extrusion processing for stabilizing rice bran requires a significant capital investment as well as high operational and equipment maintenance expenses, rendering the method unprofitable (Malekian *et al*., 2000). Therefore, it was revealed that the energy consumption of continuous IR stabilization was identical to that of extrusion. It can be inferred that IR stabilization of rice bran is appropriate for industrial use in terms of energy

Table 2: Responses of infrared treated rice bran with independent variables.

Run	Independent variables				Dependent variables		
	Power density (W/m^2)	Moisture (%)	Thickness (cm)	Time, (min)	Capacity (kg/h)	Energy demand (kWh)	FFA (%)
1	300 (-1)	12 (-1)	0.5 (-1)	3 (-1)	17.87	0.004	11.724
2	450 (0)	21 (+1.682)	0.75 (0)	4 (0)	20.10	0.01	13.94
3	600 (+1)	12 (-1)	1 (+1)	5 (1)	21.45	0.014	7.016
4	300 (-1)	18 (+1)	1 (+1)	5 (1)	21.45	0.011	13.74
5	600 (+1)	18 (+1)	1 (+1)	5 (1)	21.45	0.015	13.625
6	450 (0)	15 (0)	0.25 (-1.682)	4 (0.75)	6.70	0.004	6.15
7	300 (-1)	12 (-1)	1 (+1)	5 (1)	21.45	0.01	11.25
8	450 (0)	9 (-1.682)	0.75 (0)	4 (0.75)	20.10	0.006	8.54
9	600 (+1)	12 (-1)	0.5 (-1)	3 (0.5)	17.87	0.006	5.01
10	450 (0)	15 (0)	0.75 (0)	2 (-1.682)	40.21	0.005	12.71
11	600 (+1)	18 (+1)	1 (+1)	3 (-1)	35.75	0.01	14.59
12	300 (-1)	18 (+1)	0.5 (-1)	5 (+1)	10.72	0.01	9.164
13	300 (-1)	18 (+1)	1 (+1)	3 (-1)	35.75	0.006	14.98
14	450 (0)	15 (0)	0.75 (0)	4 (0)	20.14	0.013	4.012
15	450 (0)	15 (0)	0.75 (0)	4 (0)	20.14	0.012	4.125
16	450 (0)	15 (0)	0.75 (0)	4 (0)	20.14	0.011	4.134
17	450 (0)	15 (0)	1.25 (+1.682)	4 (0)	33.51	0.011	13.954
18	150 (-1.682)	15 (0)	0.75 (0)	4 (0)	20.14	0.006	15.06
19	600 (+1)	12 (-1)	1 (+1)	3 (-1)	35.75	0.009	10.162
20	300 (-1)	12 (-1)	1 (+1)	3 (-1)	35.75	0.006	13.962
21	300 (-1)	18 (+1)	0.5 (-1)	3 (-1)	17.87	0.006	12.06
22	450 (0)	15 (0)	0.75 (0)	6 (+1.682)	13.40	0.012	10.94
23	600 (+1)	18 (+1)	0.5 (-1)	5 (+1)	10.72	0.011	6.94
24	600 (+1)	12 (-1)	0.5 (-1)	5 (+1)	10.72	0.008	3.92
25	450 (0)	15 (0)	0.75 (0)	4 (0)	20.14	0.012	5.0128
26	750 (+1.682)	15 (0)	0.75 (0)	4 (0)	20.14	0.017	4.123
27	450 (0)	15 (0)	0.75 (0)	4 (0)	20.14	0.013	4.052
28	300 (-1)	12 (-1)	0.5 (-1)	5 (+1)	10.72	0.006	8.125
29	450 (0)	15 (0)	0.75 (0)	4 (0)	20.14	0.012	4.129
30	600 (+1)	18 (+1)	0.5 (-1)	3 (-1)	17.87	0.009	13.064

Where, A- Power density (W/m^2); B- Moisture content (%); C- Thickness (cm); D- Time (min); C.M- Capacity of the machine, (kg/h); E- Efficiency of the machine (%); E.D- Energy demand (kWh); F- Free fatty acid content, (%).

efficiency, even if the energy consumption of IR stabilization relies on the type and quantity of IR emitters, the bran feeding capacity and the dimensions of the belt.

The experimental values can be effectively fitted by the quadratic model (p-0.001). The capacity had been significantly impacted by the linear terms of the independent variables, power density, thickness and time, as shown by the F-value (23.86) and the interaction terms between the squares of the variables are significant (p-0.001).

Energy demand =

$$-0.056+0.0001X_1+0.031X_3+0.006X_4+0.000012X_1X_2-0.00075X_2X_3+0.000063X_2X_4+0.0022X_3X_4-0.000117X_1^2-0.0188X_3^2-0.00092X_4^2 \quad ...(2)$$

The adjusted R^2 of 0.9169 agrees well with the predicted R^2 of 0.7890. The APR (17.551) confirmed that the model has sufficient accuracy and reliability.

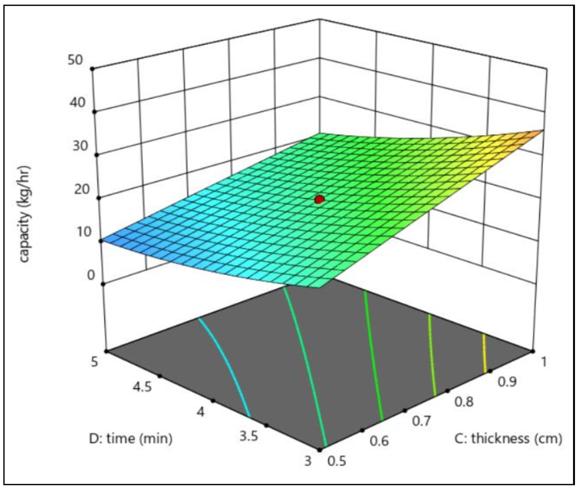

Fig 2: Response surface plot of capacity as a function of thickness, time.

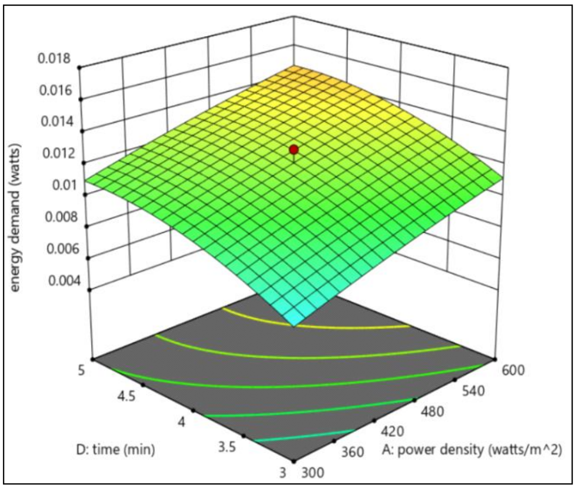

Fig 3: Response surface plot of energy demand as a function of time and power density.

Free fatty acid response to independent variables

Fig 4 and 5 depict the model-predicted response surfaces for independent variables on FFA. The FFA decreased while rising power density and time at the constant thickness and moisture content, however, the trend of the graph is nonlinear as seen in Fig 4. Better lipase inactivation resulted through rising power density and infrared exposure time, but treated bran exhibits undesirable visual and sensory changes. To prevent undesirable changes in rice bran, exposure time can be increased at low radiation intensities or decreased at elevated radiation intensities. Yilmaz *et al*. (2014) reported that stabilization between 200-400 W infrared radiation for 10 min is not enough to inhibit hydrolytic rancidity, stabilization at these powers levels may take longer time to achieve better results. Short process time of 1 min was not sufficient to inactivate lipases even at high radiation intensities, considering stabilization between 800 and 900 W is an unacceptable strategy. Moreover, process durations longer than 1 min generated unpleasant sensory and visual changes in the bran.

At constant power density and time, FFA increased with increase in thickness and moisture content as shown in Fig 5. The FFA content was low at lower bed thickness and moisture content and found to increase relatively at a slower rate as thickness and moisture content rises to 0.8 cm and 15% respectively, further rise in bed thickness and moisture content caused rapid increase in the rate of FFA content. Since infrared radiation has a lower penetration depth, increasing the thickness of the bed causes uneven exposure of the rice bran along the bed thickness, resulting variation in the rice bran-free fatty content. Sandu, 1986 reported

Table 3: Optimization criteria for various inputs and outputs variable.

Variables	Goal	Importance
A: power density, W/m^2	in range	+++
B: moisture, %	in range	+++
C: thickness, cm	in range	+++
D: time, min	in range	+++
Capacity, kg/h	maximize	++
Efficiency, %	maximize	+++++
Energy demand, kWh/kg	minimize	+++
FFA, %	minimize	+++++

Table 4: Changes in FFA of infrared stabilized rice bran during the storage.

Rice bran	FFA (Initial)	10 days	20 days	30 days
Raw rice bran	3.32	7.24	14.58	22.08
600 W/m^2, 12% mc, 0.5 cm thickness for 3 min	3.92	4.12	4.89	5.56
700 W/m^2, 15% mc, 0.75 cm thickness for 4 min	5.012	5.65	6.12	8.14
450 W/m^2, 15% mc, 0.25 cm thickness for 4 min	4.123	5.12	5.84	7.54

that, even with short wavelength infrared radiation, the depth of penetration reported is relatively low, with depths seldom exceeding a few thousandths of an inch.

According to the model (F-value: 23.56), the FFA content had been substantially influenced by power density, moisture content, thickness and time and the interaction terms of the squares of the variables are significant (p 0.001). The nonlinear second-order regression equation is illustrated below:

$$FFA = 123.32-0.108\,X_1-6.473\,X_2-38.45\,X_3-16.94\,X_4+0.000065\,X_1^2+0.194\,X_2^2+23.31\,X_3^2+1.900\,X_4^2 \quad ...(3)$$

The adjusted R2 of 0.9159 and the predicted R2 of 0.7496 are reasonably compatible. The APR (14.625) greater than 4 indicates the experiment's and model's sufficient accuracy and reliability.

Optimum conditions

To ensure maximum capacity, efficiency and minimum energy demand and FFA, optimal conditions for continuous infrared rice bran stabilizer were established. The second-order polynomial regression equations were solved in Design Expert 11 using sequential quadratic programming. The optimum values obtained by substituting the respective coded values are 600W, 12% moisture content, 0.5cm thickness and 3 min exposure time. At these optimum conditions, capacity, efficiency, energy demand and FFA were 17.85 kg/h, 20.12%, 0.006kW-h/kg and 5.01% respectively.

Changes in FFA of infrared stabilized rice bran during the storage

The best sample obtained in optimization (600W, 12% moisture content, 0.5 cm thickness and 3 min time) was kept for storage in zip lock polyethylene packs at 4°C. During storage, the FFA content of rice bran was studied at 10 days intervals for 30 days.

The FFA content of raw rice bran increased from 3.32% initiallyto 22.08% at the end of the month during storage at 4°C. The FFA content of rice bran IR stabilized at different treatment conditions was below 6% after treatment (Table 4). However, the FFA level of rice bran stabilized at 450 Wm^{-2} for 4 min and 700 W/m^2, 15% mc, 0.75 cm was above 6% after a month of storage. Also, the FFA content of rice bran stabilized at 600 W/m^2, 12% mc, 0.5 cm thickness for 3 min was 5.56% after 30 days of storage. Considering the initial FFA level of 3.32%, it can be stated that IR stabilization is effective in terms of preventing hydrolytic rancidity and that, by optimizing the operational parameters of stabilization; the shelf life of rice bran can be extended. Literature data on the FFA content of rice bran are highly variable. In raw bran, FFA increased rapidly throughout the course of 4 weeks of storage at 25°C, according to (Ramezanzadeh, 1999). Malekian *et al*. (2000) reported that the raw bran held in zip-lock bags for eight weeks had a rise in FFA content from 3.7 to 22.2%. In raw rice bran, FFA content was found to be 9.5% initially, raised to 96.8% over 345 days of storage (Mujahid, 2005).

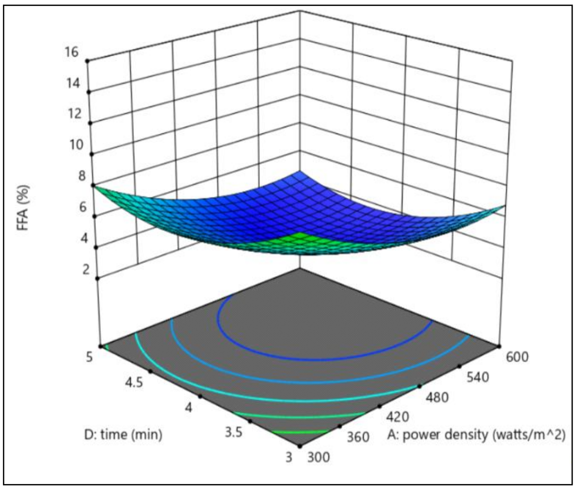

Fig 4: Response surface plot of FFA of rice bran as a function of power density, time.

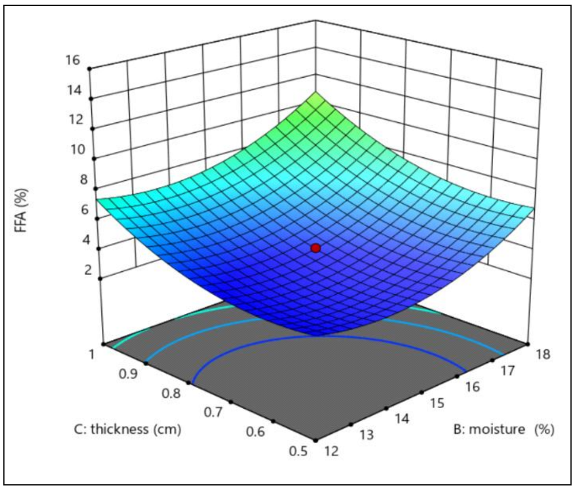

Fig 5: Response surface plot of FFA as a function of moisture content, thickness.

CONCLUSION

A continuous infrared rice bran stabilizer has been developed and response surface methodology was effectively applied to determine optimal infrared radiation treatment conditions for stabilizing rice bran while using capacity, efficiency, energy demand and FFA content as responses. The results indicated that the 600 W power, 12 per cent moisture content, 3 mm thickness and 3.0 minutes exposure time were the ideal treatment conditions for stabilizing rice bran. The capacity, efficiency, energy demand and FFA under these optimum conditions were 17.85 kg/h, 20.12 per cent, 0.006 kW-h/kg and 5.01 per cent, respectively. After 30 days of storage, the FFA content of raw rice bran increased from 3.32 per cent to 5.56 per cent.

Conflict of interest: None.

REFERENCES

AOAC, (1984). Official Methods of Analysis, Association of Official Analytical Chemists (AOAC), Washington DC. 1-50.

AOAC, (1990). Official Methods of Analysis, 15th ed. Washington, DC: Association of Official Analytical Chemist.

Dhingra, D., Chopra, S. and Rai, D.R. (2012). Stabilization of raw rice bran using ohmic heating. Agricultural Research. 1(4): 392-398.

Eromosele, I.C., Eromosele, C.O. (1994). Studies on the chemical composition and physicochemical properties of seeds of some wild plants. Plant Foods for Human Nutrition. 46: 361-365.

Esa, N.M., Ling, T.B. and Peng, L.S. (2013). By-products of rice processing: An overview of health benefits and applications. Rice Res. 1: 1-11. doi: 10.4172/jrr.1000107.

Irakli, M., Kleisiaris, F., Mygdalia, A. and Katsantonis, D. (2018). Stabilization of rice bran and its effect on bioactive compounds content, antioxidant activity and storage stability during infrared radiation heating. Journal of Cereal Science. 80: 135-142.

Ju, Y.H. and Vali, S.R. (2005). RBO as a potential resource for biodiesel: A review. Journal of Scientific and Industrial Research. 64: 866-88.

Kahlon, T.S., Chow, F.I., Sayre, S.R. and Betschart, A.A. (1992). Cholesterollowering in hamsters fed rice bran at various levels, defatted rice bran andrice bran oil. J. Nutr. 122: 513-519.

Kathiravan, K., Kaur, K.H., Jun, S., Joseph, I., Ali, D. (2007). Infrared heating in food processing: An overview. Compr. Rev. Food Sci. Food Saf. 7: 2-13.

Little, T.M. and Hills, F.J. (1982). Agricultural Experimentation: Design and Analysis. International Biometric Society.

Malekian, F., Rao, R., Prinyawiwatkul, W., Marshall, W.E., Windhauser, M. and Ahmedna, M. (2000). Lipase and lipoxygenase activity, functionality and nutrient losses in rice bran during storage. Aricultural Center, Louisiana Agricultural Experiment station, Baton Rouge. Bulletin No. 870: 1-68.

Mendenhall, W. (1975) Introduction to Probability and Statistics. 4th Edition, North Settuate, M.A., Duxbury Pres, USA.

Mujahid, A., Haq, I.U., Asif, M. and Gilani, A.H. (2005). Effect of various processing techniques and different levels of antioxidant on stability of rice bran during storage. Journal of Science and Food Agriculture. 85: 847-852.

Patil, S.S., Kar, A., Debabandy Mohapatra, D. (2016). Stabilization of rice bran using microwave: Process optimization and storage studies. Food Bioprod. Process. 99: 204-211.

Pradeep, P.M., Jayadeep, A., Guha, M., Singh, V. (2014). Hydrothermal and biotechnological treatments on nutraceutical content and antioxidant activity of rice bran. J. Cereal. Sci. 60: 187-192.

Ramezanzadeh, F.M., Rao, R.M., Prinyawiwatkul, W., Marshall, W.E. and Windhauser, M. (1999). Effects of microwave heat, packaging and storage temperature on fatty acid and proximate compositions in rice bran. Journal of Agriculture Food Chemistry. 48: 464-467.

Rosniyana A., Hashifah, M.A. and Shariffah Norin, S.A. (2009). Nutritional content and storage stability of stabilised rice bran-MR 220. Journal of Tropical Agriculture and Food Science. 37(2): 163-170.

Sakai, N., Hanzawa, T. (1994). Applications and advances in far-infrared heating in Japan. Trends Food Sci. Technol. 5: 357-62.

Sandu, C. (1986). Infrared radiative drying in food engineering: A process analysis. Biotechnol Prog. 2(3): 109-19.

SEA, (2017). https://www.thehindubusinessline.com/economy/agri-business/scope-to-boost-rice-bran-oil-output-demand-sea/article9830157.ecexvi.

Sharma, H.R., Chauhan, G.S. and Agrawal, K. (2004). Physico-chemical characteristics of rice bran processed by dry heating and extrusion cooking. International Journal of Food Properties. 7: 603-614.

Silva, M.A., Sanches, C., Amante, E.R. (2006). Prevention of hydrolytic rancidity in rice bran. J. Food. Eng. 75: 487-491.

Skjöldebrand, C. (2001). Infrared heating. In: Thermal Technologies in Food processing. [Richardson P., (eds)]. CRC Press; New York, NY, USA.

Thanonkaew, A., Wongyai, S., McClements, D.J., Decker, E.A. (2012). Effect of stabilization of rice bran by domestic heating on mechanical extraction yield, quality and antioxidant properties of cold-pressed rice bran oil (*Oryza sativa* L.). LWT Food Sci. Technol. 48: 231e236.

Wang, T., Khir, R., Pan, Z., Yuan, Q. (2017). Simultaneous rough rice drying and rice bran stabilization using infrared radiation heating. LWT-Food Sci. Technol. 78: 281-288.

Yan, W., Liu, Q., Wang, Y., Tao, T., Liu, B., Liu, J., Ding, C., (2020). Inhibition of lipid and aroma deterioration in rice bran by infrared heating. Food and Bioprocess Technology. 12(2): 1677-1687.

Yılmaz, N. (2016) Middle infrared stabilization of individual rice bran milling fractions. J. Food. Chem. 190: 179-185.

Yilmaz, N., Tuncel, N.B. and Kocabiyik, H. (2014). Infrared stabilization of rice bran and its effects on ã oryzanol content, tocopherols and fatty acid composition. Journal of the Science of Food and Agriculture. 94(8): 1568-1576.

Yu, C.W., Hu, Q.R., Wang, H.W., Deng, Z.Y. (2019). Comparison of 11 rice bran stabilization methods by analyzing lipase activities. J. Food. Process. Preserv. 00: e14370.